5G-PPP 5G ESSENCE: Embedded Network Services for 5G Experiences

Goals of the project

5G ESSENCE (Grant Agreement No.761592) "addresses" the paradigms of Edge Cloud computing and Small Cell-as-a-Service (SCaaS) by fuelling the drivers and removing the barriers in the Small Cell (SC) market, forecasted to grow at an impressive pace up to 2020 and beyond, and to play a "key role" in the global 5G ecosystem. The original 5G ESSENCE framework proposes and designs a highly flexible and scalable platform, able to support new business models and revenue streams by creating a "neutral host" market and reducing operational costs, thus providing new opportunities for ownership, deployment, operation and amortisation.

The technical approach exploits the benefits of the centralisation of Small Cell functions as scale grows through an edge cloud environment based on a two-tier architecture, that is: (i) a first distributed tier for providing low latency services, and; (ii) a second centralised tier for providing high processing power for computing-intensive network applications (more details are also given in Figure 2). This allows decoupling the control and user planes of the Radio Access Network (RAN) and achieving the benefits of Cloud-RAN without the enormous fronthaul latency restrictions. The use of end-to-end (E2E) network slicing mechanisms will allow sharing the 5G ESSENCE infrastructure among multiple operators/vertical industries and, *consequently*, customising its capabilities on a *per-tenant* basis. The versatility of the architecture is enhanced by high-performance virtualisation techniques for data isolation, latency reduction and resource efficiency, and by orchestrating lightweight virtual resources enabling efficient Virtualised Network Function (VNF) placement and live migration.

The 5G ESSENCE project leverages knowledge, SW modules and prototypes from various 5G-PPP Phase-1 projects (with the "SESAME" project[1] being particularly relevant). Building on these foundations, very ambitious objectives are targeted, culminating with the prototyping and demonstration of 5G ESSENCE system in **three real-life use cases associated to vertical industries**, that is: (i) Edge Network Acceleration with local video production and distribution in a crowded event; (ii) Mission Critical (MC) applications for Public Safety (PS) communications providers, *and*; (iii) In-Flight Entertainment and Connectivity (IFEC) communications, as depicted in Figure 1.

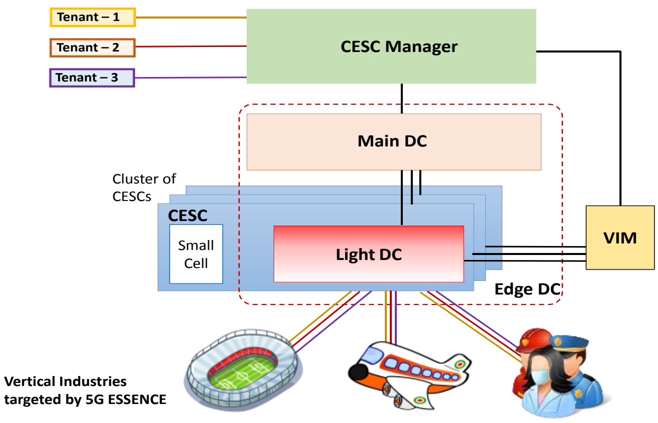

Figure 1: 5G ESSENCE high-level architecture and vertical applications.

At the network's edge, each **Cloud-Enabled Small Cell (CESC)** is able to host one -or more- service VNFs, directly applying to the users of a specific operator that has accessed the related platform. The CESCS are devices that include both the processing power platform and the small cell unit. They can be deployed at low- and medium-scale venues and scan support multiple network operators (i.e., they promote the so called as

[1] 5G-PPP/H2020 SESAME (Small cEllS coordinAtion for Multi-tenancy and Edge services) Project, Grant Agreement No.671596. http://www.sesame-h2020-5g-ppp.eu/

"multitenancy" feature). Furthermore, CESCs can support network services and applications at the edge of the network.
The Light Data Centre (DC) can be used for implementing different functional splits of the SCs as well as for supporting the mobile edge applications of the involved end-users. At the same time, 5G ESSENCE proposes the development of SC management functions as VNFs, which run in the Main Data Centre and coordinate a fixed pool of shared radio resources, instead of considering that each small cell station has its own set of resources. These VNFs can be instantiated inside the Main DC and be parts of a Service Function Chaining (SFC) procedure.
The CESC Manager (CESCM) is responsible for coordinating and supervising the use, the performance and the delivery of both radio resources and services. It controls the interactions between the infrastructure (i.e.: CESCs and Edge DC) and the network operators. In addition, it handles related Service Level Agreements (SLAs). As of the proposed architectural approach, the CESCM also encompasses telemetry and analytics as fundamental tools for efficiently managing the overall network. The Virtualised Infrastructure Manager (VIM) is responsible for controlling the NFV (Network Function Virtualisation) Infrastructure (NFVI), which includes the computing, storage and network resources of the Edge DC.
It should be mentioned that 5G ESSENCE does not only propose the development and adaptation of the multitenant CESC platform, the virtualisation infrastructure and the centralisation of the software-defined (SD) radio resource management described above; it also addresses several aspects that affect performance in 5G virtualised environments such as virtual switching, VNF migration and Machine Learning (ML) algorithms, which allow orchestrating diverse types of lightweight virtual resources.

Description of the 5G ESSENCE Novel Architecture

In the 5G ESSENCE approach, the Small Cell concept is evolved as not only to provide multi-operator radio access but also, to achieve an increase in the capacity and the performance of current RAN infrastructures and to extend the range of the provided services, while maintaining its agility. To achieve these ambitious goals, the 5G ESSENCE project leverages the paradigms of RAN scheduling and, *additionally*, provides an enhanced, edge-*based*, virtualised execution environment attached to the small cell, taking advantage and reinforcing the concepts of MEC (Multi-Access Edge Computing) and network slicing.

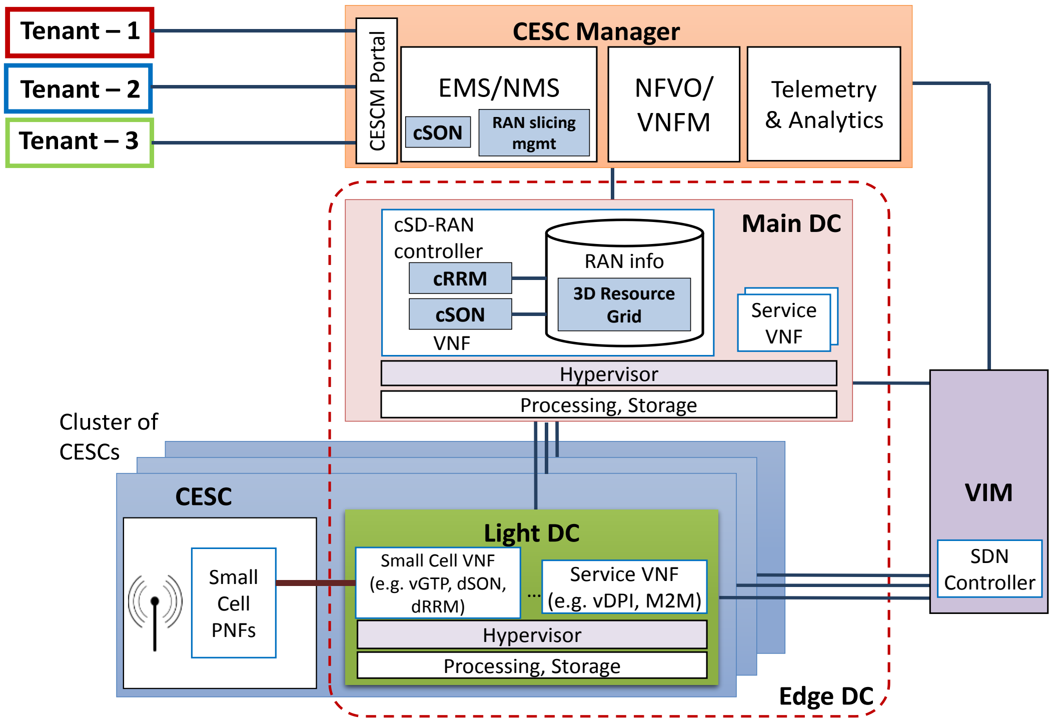

Figure 2: 5G ESSENCE novel architecture.

The **5G ESSENCE architecture**[2] (see Figure 2) allows multiple network operators (or "tenants") to provide services to their users through a set of CESCs deployed, owned and managed by a third party (i.e., the CESC provider). In this way, operators can extend the capacity of their own 5G RAN in areas where the deployment of their own infrastructure could be expensive and/or inefficient; this would be the case of, *for example*, highly dense areas where massive numbers of Small Cells would be needed to provide the expected services.

As already mentioned, the 5G ESSENCE platform is equipped with a two-tier virtualised execution environment. The first tier (i.e.: the Light DC hosted inside the CESCs) is used to support the execution of VNFs for carrying out the virtualisation of the Small Cell access. In this regard, network functions supporting traffic interception, GTP (General Packet Radio Service Tunnelling Protocol) encapsulation/decapsulation and some distributed RRM (Radio Resources Management) /SON (Self-Organised Network) functionalities can be executed therein. Specific VNFs that require low processing power such as, *for example*, a Deep Packet Inspection (DPI), a Machine-to-Machine (M2M) Gateway and so on, could also be hosted here. The connection between the Small Cell Physical Network Functions (PNFs) and the Small Cell VNFs can be realised through, *for example*, the network Functional Application Platform Interface (nFAPI). Finally, backhaul and fronthaul transmission resources will be part of the CESC, allowing for the required connectivity. The second cloud tier (i.e., the Main DC) will be hosting more computation intensive tasks and processes that need to be centralised in order to have a global view of the underlying infrastructure. This encompasses the centralised Software-Defined Radio Access Network (cSD-RAN) controller which will be delivered as a VNF running in the Main DC and makes control plane decisions for all the radio elements in the geographical area of the CESC cluster, including the centralised Radio Resource Management (cRRM) over the entire CESC cluster. Other potential VNFs that could be hosted by the Main DC include security applications, traffic engineering, mobility management and, *in general*, any additional network E2E services that can be deployed and managed on the 5G ESSENCE virtual networks, effectively and on-demand.

The CESC is meant to accommodate multiple operators (tenants) by design, offering Platform as-a-Service (PaaS), capable of providing the deployed physical infrastructure among multiple network operators. It exposes different views of the network resources, that is: per-tenant small cell view and physical small cell substrate. The CESCM is the central service management and orchestration component in the respective architecture. In a more generalised context, it integrates all the traditional network management elements and the novel recommended functional blocks to realise NFV operations. The CESCM functions can be developed upon the services provided by the VIM for appropriately managing, monitoring and optimising the overall operation of the NFVI resources (i.e.: computing, storage and network resources) at the Edge DC. The role of VIM is essential for the deployment of NFV services and to form and provide a layer of NFV resources to be made available to the CESCM functions.

Main Objectives and Actual Achievements of the project

The 5G ESSENCE project is an innovative effort, towards achieving the following ***objectives***:

- Specification of the critical architectural enhancements (originating from prior 5G-PPP Phase-1 projects or approaches) that are needed to fully enable cloud-integrated multi-tenant small cell networking.
- Definition of the baseline system architecture and of the related interfaces for the provisioning of a cloud-integrated multi-tenant Small Cell network and a programmable Radio Resource Management controller, both customisable, on a *per vertical* basis.
- Development of the centralised SD-RAN controller, able to program the radio resources usage in a unified way for all involved CESCs.
- Exploitation of high-performance and efficient virtualisation techniques for better resource utilisation, higher throughput and less delay at Network Services (NSs) creation time.
- Development and inclusion of suitable orchestrator enhancements, for the corresponding distributed service management.
- Demonstration and evaluation of the cloud-integrated multi-tenant small cell network, via three real-life vertical industries each one proposing a meaningful use case with strong market relevance.

2 For a detailed description of the corresponding architecture and of related aspects, also see: 5G ESSENCE Deliverable 2.2 ("Overall System Architecture and Specifications"). Available at: *http://www.5g-essence-h2020.eu/Portals/0/5G%20ESSENCE_%20Deliverable%202.2_v1.1_Final.pdf?ver=2018-11-27-112117-947*

- Conduct of a market analysis and establishment of new business models, following to the technical progress of each use case; in this framework, detailed techno-economic analysis and roadmapping towards exploitation and commercialisation by industrial partners is also a high priority.
- Ensuring maximisation of 5G ESSENCE impact to the realisation of the 5G vision by establishing close liaison and interactive synergies with other 5G-PPP Phase-1 & 2 projects and the Association.

Actual ***achievements*** of the project are shortly listed as follows:

- The project has defined, assessed and further elaborated the necessary use cases, targeted by the 5G vertical industries’ demonstrations during the ongoing trials. More specifically, for all originally selected use cases there have been exact demonstration plans and descriptions of functional/non-functional requirements of the respective network services, by elaborating and refining the initial planning *-as developed in the architectural framework-* so that to effectively integrate the corresponding services. Effort has also been performed upon defining suitable proof-of-concept (PoC) for the exploitation of the participating 5G ESSENCE technologies, in all corresponding scenarios.
- Furthermore, a proper test strategy has been proposed and realised for “adjusting” depth and coverage of testing to available resources. More specifically, we have defined a set of functional tests and KPIs in order to evaluate the relevance of the proposed scenarios and architecture *from one hand*, and the coherence of the integration and testing process *on the other*. Detailed demonstrations have been performed and are ongoing towards further validating the context of each specific use case.
- In addition, the 5G ESSENCE has established a detailed system architecture and corresponding interfaces for the provisioning of a cloud-integrated multi-tenant SC network and a programmable RRM controller, conformant to the well-defined project objectives. The original architecture has thus been re-assessed, updated and further extended, via the inclusion of more attributes and features (such as telemetry, data analytics and improved orchestration).
- The project has also described and analysed the current status of the development of methods for highly dynamic virtualisation solutions and for their applicability within the project’s framework.
- Another set of achievements has been about the successful description and the overall design of the centralised SD-RAN Controller, together with different network interfaces used in the solution as well as with methods and mechanisms for network slicing, optimisation and implementation of a novel radio resource management framework.
- By late of 2019, the 5G ESSENCE also aims to “map” the key exploitable innovations to the standardisation objectives.
- Moreover, the well-planned dissemination and communication strategy continues to be valid, ensuring that the project achieves maximum visibility and that it has an impact within the business and scientific community, thus effectively accelerating the adoption of the various 5G ESSENCE research and innovation outputs.

Fundamental Use Cases of the 5G ESSENCE project

The 5G ESSENCE project develops three real-life use cases (UCs), directly associated to vertical industries. These are listed, in brief, as follows:

Use Case 1: Edge Network Acceleration with local video production and distribution in a crowded event: The 5G ESSENCE demonstrates a combined 5G-*based* video production and video distribution towards delivering benefits to both media producers and mobile operators, being able to offer enriched event experience to their subscribers. The production/distribution of locally generated content through the 5G ESSENCE platform, coupled with value-added services and rich user context enables secure, high-quality and resilient transmission, in real-time and with minimal latency.

Use Case 2: Mission Critical (MC) applications for Public Safety (PS) communications providers: The 5G ESSENCE involves one or more PS communications providers, able to use the resources offered by a deployed 5G ESSENCE platform for the delivery of communication services to PS organisations in a country/region. In the mission critical use case, the infrastructure owner exploits the 5G ESSENCE system capabilities to provide the required network/cloud slicing capabilities with dedicated Service Level Agreements to different types of tenants, by prioritising the PS communications providers.

Use Case 3: In-Flight Entertainment and Connectivity (IFEC) communications: The 5G ESSENCE IFEC framework focuses upon testing and validating the multi-tenancy enabled network solution for passenger connectivity and wireless broadband experience. The multi-RAT (Radio Access Technologies) CESCs can be implemented as a "set of integrated access points", deployed on-board. Since inflight entertainment has also to consider the explosive growth of multi-screen content consumption, the 5G ESSENCE CESCs will stream on demand multi-screen video content (both from on-board servers and via satellite/air-to-ground links) to the wireless devices.

In the following, we discuss each use case separately and identify major findings a related progress performed until the present day.

Use Case 1 Description

Use Case 1 (UC1) focuses upon the demonstration of a combined 5G-*based* video production and video distribution towards delivering benefits to both media producers and mobile operators (see Figure 3), thus allowing the latter to offer enriched event experience to their subscribers. The production and distribution of locally generated content through the 5G ESSENCE platform, coupled with value-added services and rich user context, enables secure high quality and resilient transmission in real-time and also ensures minimal latency. A large-scale facility (i.e.: the municipal football stadium "Stavros Mavrothalasitis" in Egaleo-Athens, Greece with a capacity of 8.000 spectators) has been available for the validation purposes. The stadium's coverage has been provided by a cluster of cloud edge-*enabled* small cells and a main DC connected to the Core Network (CN) of one telecom operator (with potential of hosting more relevant "actors") to realize services running as VNFs (see Figure 4).

This use case focuses on:

- The optimisation of 5G wireless access network by potentially applying the developed cSD-RAN controller and taking into account real time feedback of the radio channel conditions;
- the validation of real-time 3GPP eMBMS ((evolved Multimedia Broadcast Multicast Service) broadcasting capabilities in the context of a neutral host;
- the edge local traffic offloading at the stadium;
- the real-time hardware-accelerated video encoding and decoding at Main DC (video production), and;
- the development of customisable applications for viewing streams on mobile devices.

UC1 delivers benefits to media producers and (mobile) operators as it enables them to offer a highly interactive fan experience and also optimises operations by deploying "key functionalities" at the edge, that is eMBMS together with optional multitenancy support by small cells. By leveraging the benefits of SC virtualisation and radio resource abstraction, as well as by optimising network embedded cloud, it becomes possible to ease the coverage and capacity pressure on the multimedia infrastructure and also to increase security, since content remains locally. Furthermore, additional benefits for the operators and the venue owners arise such as: (i) lower latency, due to shortening the data transmission path, and; (ii maintained backhaul capacity, due to playing out the live feeds and replays locally that avoids additional strain on the backhaul network and upstream core network components.

The Edge DC is processing video content coming from cameras deployed on-site which is be sent for processing locally at the Edge (i.e., in a way quite similar to the ETSI MEC context). Then there is a local broadcasting of the video stream, by using the 3GPP eMBMS functionality. The video streams are broadcasted locally using the CESCs. Spectators are able to dynamically select between different offered broadcast streams. The main infrastructure needed for this demo is depicted in Figure 5. Following to the above concept, the participating spectators become able to dynamically select, among different offered broadcast streams. This use case demonstrates a typical MEC configuration that keeps traffic as close as possible to the end-users, allowing them to consume digital media with high quality and low latency. Supported services are: (i) Multicast Video Delivery in multi/single view; (ii) User Equipment (UE) View Switching during the video delivery; (iii) Video Delivery with handover, *and;* (iv) Unicast *vs.* Multicast Video Delivery.

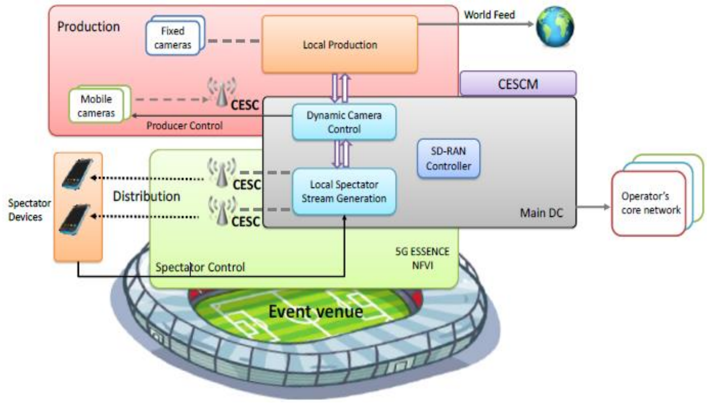

Figure 3: 5G network acceleration with local video production and distribution in a stadium.

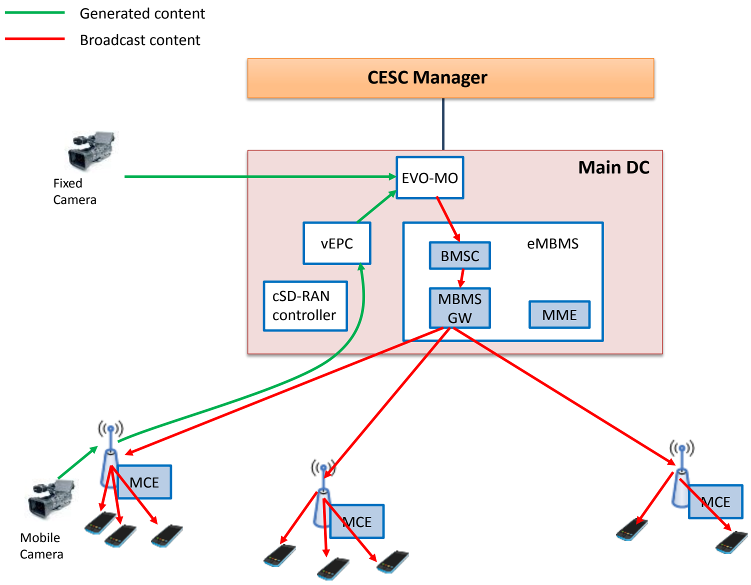

Figure 4: Overall service VNF placement.

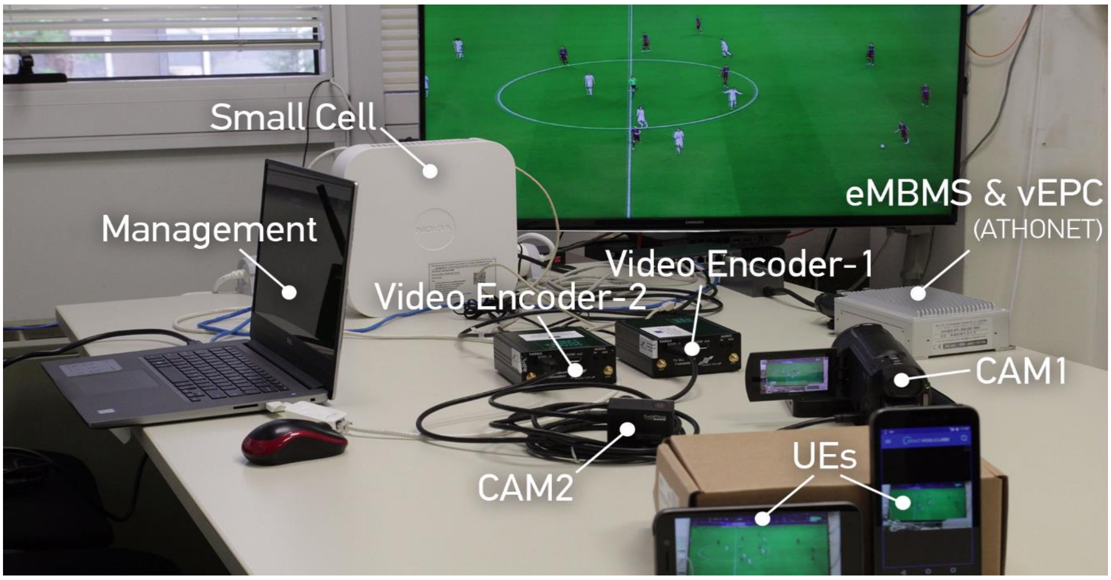

Figure 5: Main infrastructure for UC1 demo.

Two successful demos took already place in the stadium. The first demo took place in *July 2019*, during Egaleo team's training. The second one took place in *October 2019*, where two football teams had a typical 90-minutes match. The event was broadcasted via the 360^o camera to the eMBMS-enabled end-devices of the viewers. (Apart from the 5G ESSENCE partners, many external viewers also attended this latter event, including two members of the Greek Parliament, three Mayors, as well as the Deputy Minister of Digital Governance).

Use Case 2 Description

In the 5G ESSENCE original framework, the Use Case 2 (UC2) focuses upon two different public safety services, that is: (i) Mission Critical Push-To-Talk (MCPTT), and; (ii) mission-critical messaging and localisation service. The MCPTT and Chat & Localisation service allows the secure communication such as, voice calls, chats and localisation tacking between pairs and/or groups of first responders. It should be specified that for different emergency situations each service will be deployed in an isolated network slice and the necessary available resources will be allocated to ensure the functionality, connectivity and even the needed Quality of Service ((QoS). The detailed outcome of Use Case 2 will be demonstrated during the BAPCO Satellite Series 2019[3] Event, in Newcastle, UK. In this event, two different test-beds will be used to demonstrate in live the functionality of each mission critical service.

Towards performing these trials, the 5G ESSENCE platform owners provide the required network slices to different tenants. At the RAN segment, allocation of data rates is made by the SD-RAN controller in accordance with the cloud resources already allocated in the Edge DC by the VIM. In case of emergency, the CESC will "add" new resources taking into consideration the request, close-to-zero delay and maintaining the connection even if the backhaul is damaged. Moreover, in these trials the 5G ESSENCE SD-RAN controller will have the essential role of enforcing the priority access of first-responders by extending the slices to the radio part, thus creating the E2E slices that isolate those responders from other parties' communications. The isolated slices will be created and controlled by 5G-EmPOWER[4].

Figure 6 illustrates the different components involved in the service of MCPTT. Essentially, an IP Multimedia Subsystem (IMS) is implemented as a centralised subsystem attached to the Evolved Packet Core (EPC) of each operator and it operates together with the centralised nodes when HSS (Home Subscriber Server) requests are processed (e.g., during communication establishment). Therefore, Use Case 2 proposes to bring MCPTT server "near to the user", in a distributed and scalable way. This decision will reduce the latency and the computation load.
On the other hand, as of the case of the localisation and messaging service, the proposed solution (called as "FeedSync"[5]) is based on innovative publish subscribe modular solution that operates on top of the 5G ESSENCE, leveraging the flexibility of 5G architecture. More interestingly, the virtualised approach enables on-the-fly deployment of new resources close to the users, as envisaged by the original 5G ESSENCE approach. What is more, instantiated resources can be tailored to the capacity of the hosting hardware in the sense that light versions of an application are favored when it comes to instantiating services in small cells and light DC, as highlighted in Figure 7.

To demonstrate the main 5G ESSENCE features, we propose a deployment topology in three main stages, as follows: At the beginning, in a situation under normal circumstances, the system instantiates the network slices that correspond to a default service agreement. Here, the first responder only needs a reduced amount of access capacity and communication features for its normal operations. Then, triggered by an emergency incident, the first responder requires increased capacity in terms of both data rate and edge computing resources, in order to serve a higher number of communications and/or public safety users. This situation may involve a deterioration of the service for legacy users, since their network slice(s) must be reduced in order to appropriately allocate the higher priority service. Finally, in the last stage we demonstrate how our 5G architecture responds to an extreme situation of damaged infrastructure where a coverage extension is

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3 Website of BAPCO Event: *https://www.bapco.org.uk/events/british-apco-satellite-series-newcastle/* (Accessed on March 2019).

4 5G-EmPOWER is a Software-Defined Networking Platform for 5G Radio Access Networks, proving an open ecosystem where new 5G services can be tested in realistic conditions. For more details, also see: *https://5g-empower.io/*.

5 For more related information also see, *inter-alia*: *https://codex.easypropertylistings.com.au/article/28-how-to-install-and-use-feedsync*

needed. In this situation, backhaul connectivity is lost; all the resources must be dedicated to the public safety network slice whereby first responder's organisation may dynamically add new access points to the network in order to improve connectivity.

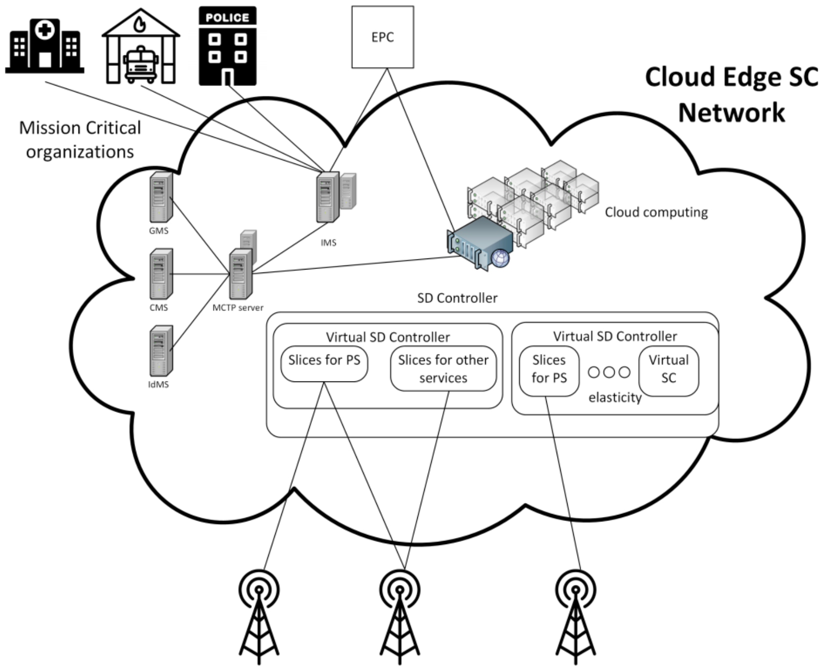

Figure 6: Components involved in a MCPTT service for public safety deployment.

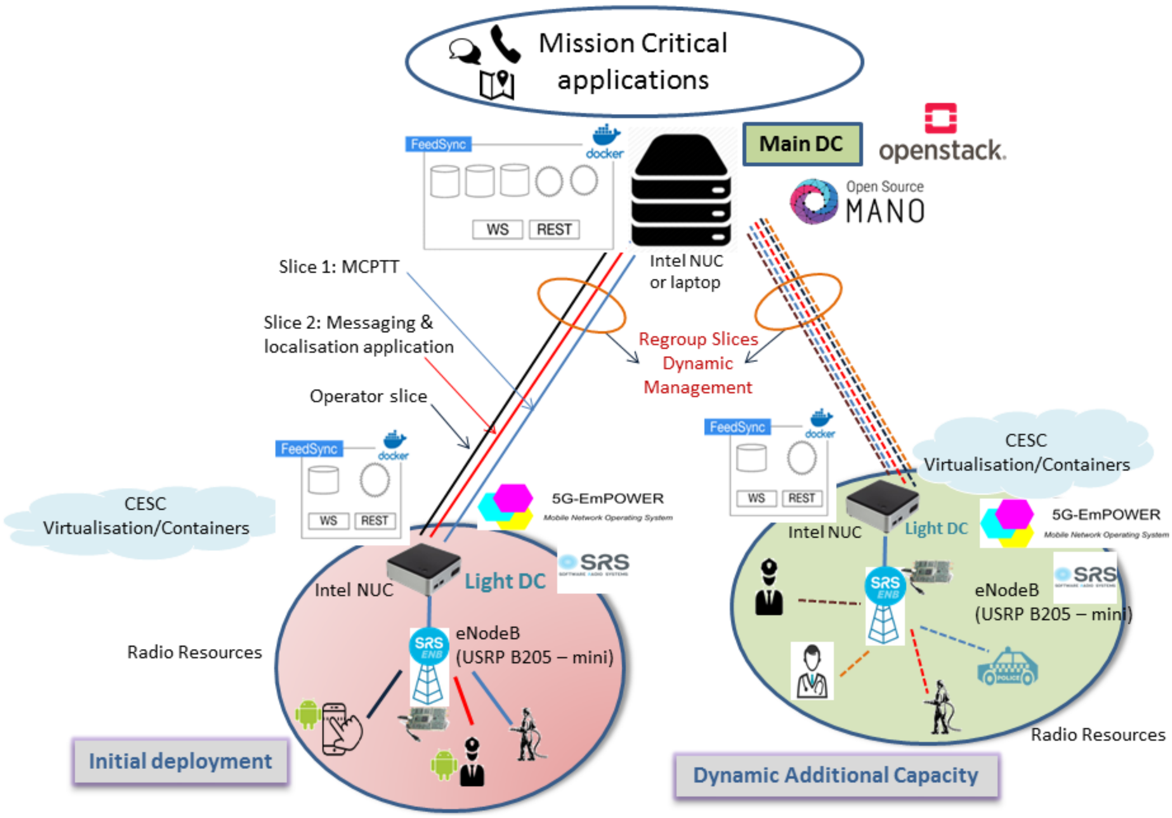

Figure 7: Architecture of messaging & localisation service.

USE Case 3 Description

The 5G ESSENCE Use Case 3 (UC3) revolves around the next generation of In-Flight Entertainment and Communications (IFEC) system on-board aircrafts, setting up the ambitious goal to include the sector of civil aviation in the 5G ecosystem by means of the 5G ESSENCE system architecture. The existing in-flight network exhibits several bottlenecks: the existing Gigabit Ethernet network connecting all the different components of the IFEC system (i.e. screens, wireless Access Points (APs) and servers), the limited number of APs and the satellite link backhaul for connectivity to the ground. For these reasons, the multi-tier edge cloud infrastructure developed by the 5G ESSENCE can improve the current limitations and bring the flexibility to add new (network) services on-board. Moreover, following the 5G ESSENCE approach, the aircraft becomes a self-contained 5G network edge wherein computing, storage and networking resources are deployed. Likewise, the IFEC system will also leverage on the paradigm of Multi-Access Edge Computing (MEC) to cope with a resource constrained environment, where virtualised network functions are orchestrated along with the services selected for this UC's demonstration.

More specifically, the 5G ESSENCE UC3 is based upon the following main pillars:

- *Multi-tenancy* in the aircraft network hosting multiple operators and service providers embracing the concept of Neutral Host. UC3 adheres to a Multi-Operator Core Network approach, in which one Core Network will be deployed for crew operations and another CN for passengers' IFEC.
- On-board *multi-RAT* communication; namely, aeronautical certified Wi-Fi APs and mobile network technology enabled small cells.
- *cSD-RAN controller*, which is tasked to manage wireless technologies in licenced/unlicensed spectrum for the IFEC use case.
- Evolved in-flight applications such as *video transcoding, content caching* on-board, *network slicing* and *efficient multicast* for content delivery.
- *Edge Cloud Monitoring (Telemetry), Analytics and Orchestration systems* integrated in an innovative framework.

All the above-mentioned pillars are the enablers of the final demonstration, which will be held by the end of *November 2019* in Munich, Germany. The outcome of the third demonstration of 5G ESSENCE will be a video recorded at the ZII's Airbus A320 cabin mock-up (refer to Figure 8) and it will show all the phases of a flight and how the upgrades proposed by the project can bring the current IFEC systems to an enhanced level. Currently, 5G ESSENCE partners dedicated in UC3' s implementation are working on the integration between the different components in the testbed, which follows the system architecture depicted in Figure 9, and is physically located at ZII's wireless RTD laboratory.

Finally, 5G ESSENCE UC3-related effort has already provided intermediate successful demonstrations, which are available on-line. First, the efficient multicast and network slicing features have been presented during the first-year review of the project in Brussels, Belgium, on *September 2018*. A link showing part of this demonstration is available here. Later, the video transcoding service for IFEC scenarios was shown at EuCNC 2019 in Valencia, Spain, on *June 2019* (The video shown during the EuCNC 2019 Conference can be found here). There are other multiple successes, such as the MOCN (Multi-Operator Core Network) deployment or the zero-touch-orchestration methodology already available in the UC3 group, which have not been individually shown yet in public fares but will be exhibited during the scheduled *November's 2019* demonstration.

Figure 8: Airbus A320 cabin mock-up at ZII’s premises.

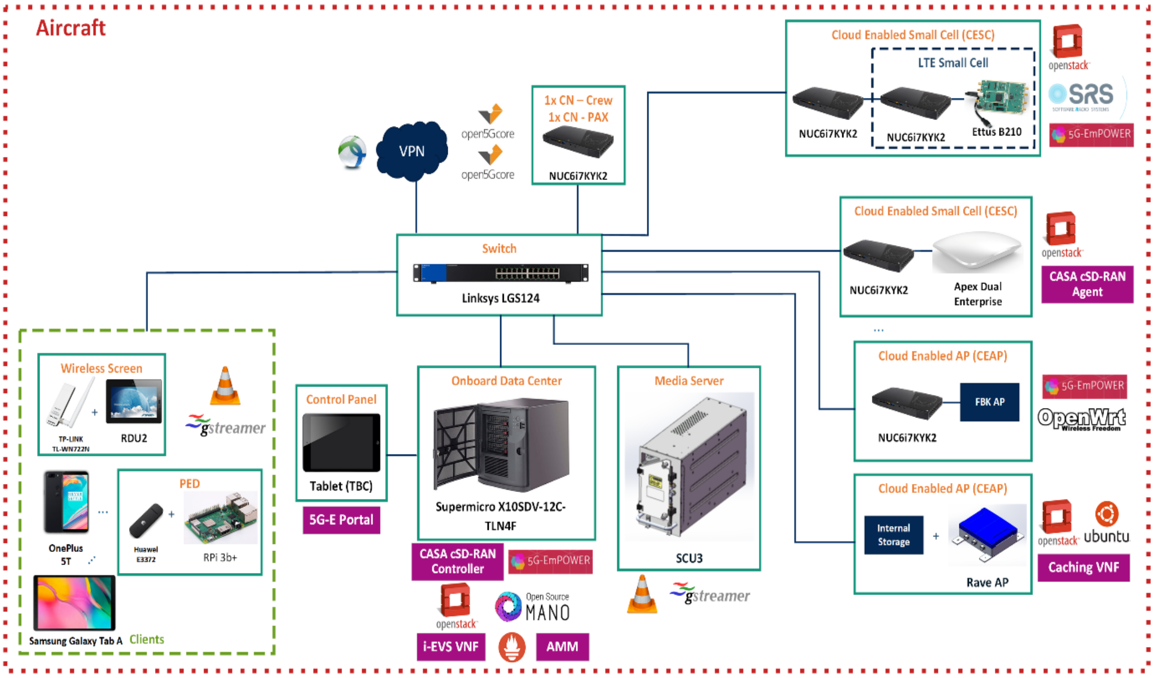

Figure 9 : UC3 testbed architecture.